Performance Evaluation of DC Motor Speed control system using Fuzzy Logic Controller

Emmanuel E. Effiong, Ekpenyong N. Oku, Okon Ekpenyong, Peter Onwe

Abstract— **The direct current (DC) motors are extensively used in domestic appliances and industrial equipment. DC motors are efficient, reliable and controllable in an aspect of speed control. This paper aim is to investigate the dynamic behavior of a separately excited DC motor and propose a fuzzy logic controller for its efficient control. A DC motor model is developed to simulate the behavior of the motor. Fuzzy logic controller is designed and implemented in MATLAB/Simulink software. The performance of the controller is evaluated using variable load condition and transient response to reference speed, and the simulation results for Fuzzy logic controller and PID controller were compared and the results show that the proposed fuzzy logic controller provides better control of the DC motor as the fuzzy logic controller can effectively control the DC motor. The findings have significant implications for the industrial control of DC motors, especially in the application areas like automation and robotics**

Index Terms— **Fuzzy logic controller, DC motor, PID controller, Fuzzy logic controller**

I. INTRODUCTION

The high-performance DC motor drives in factories are used more often due to its excellent electrical characteristics such as high a starting torque, high response performance. DC motors are extensively used in industrial and domestic appliances They are found I the following applications: electric traction, electric train, steel rolling mills, cutting tool, robotic manipulators, overhead cranes, guided vehicles, home appliances and other speed and position applications [1]. DC motors are used for adjustable speed applications due to its good speed control, controllable torque and high reliability. Separately excited DC motor (SEDCM) is suitable for variable speed drives application. As voltage is supplied directly to the field winding of the motor. Basically, there are three speed control techniques used commonly; Field resistance control, Armature resistance control and armature voltage control method. In armature-controlled Dc drive, the speed is directly proportional to applied armature voltage of the DC motor. So, for armature-controlled DC motor, the motor is controllable over wide range through proper adjustment of terminal voltage [2]. Various feedback control systems have been developed whose aim is to achieve precise and fast tracking of reference speed with little overshoot, little or no steady state error. PID (proportional -Integral-Derivative) controller is common and very popular in industrial control applications due to the following reasons viz: simple model, robustness, high reliability and elimination of steady state error. However, conventional controllers (PI, PD, PID) is very difficult and time consuming to tune mainly under varying load condition[1]. There have been so many schemes for speed control of separately excitedly motor such as PID, Fuzzy logic controller, optimal Linear Quadratic Regulator (LQR) control ,Artificial intelligence technique, etc. since all control systems suffer from undesirable performance indices such as longer settling time, large overshoot, vibrations and instability while going from one state to another state. As real-world systems are non-linear, making accurate modelling difficult and costly [3]. FLC speed controlled-DC motor perform better than PID speed-controlled DC motor due to little settling time, zero overshoot, and robustness when load is applied [4][5]. In Kumar.S. B et al paper presents comparison of performance of PID and FLC in speed control of Dc motor using MATLAB/SIMULINK environment, the simulation result shows that FLC gives better response compared to PI and PID controller.[6]. In this paper, model of SEDCM is modelled using armature-controlled scheme is fed with fixed dc and the motor output is speed of shaft that rotates the load, with Fuzzy logic controller (FLC) designed for speed control using Mamdani Fuzzy Inference System (FIS). The PID controller is also developed using MATLAB/SIMULINK software for comparison of speed transient response when using the two controllers

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II. METHODOLOGY

A. Mathematical modelling of armature- controlled DC motor System

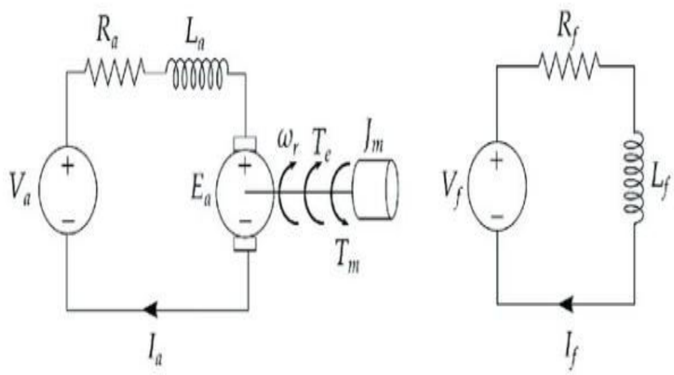

Fig 1 equivalent circuit of separately excited DC motor [7]

The DC motor is mathematically modelled by taking into consideration the torque and rotor angle relationship. According to the Kirchhoff's voltage law on armature circuit. The armature voltage of the DC motor is described as:

$$V_a = L_a\left(\frac{di_a}{dt}\right) + R_a i_a + E_g \tag{1}$$

The back emf voltage (E_g) is proportional to the angular speed (ω) of the rotor in the motor, expressed as

$$E_g = K_v \omega i_f = K_b \omega \qquad (2)$$

The relation between steady state motor torque T_m, armature current (i_a) and torque constant K_t is given as,

$$T_m = K_t i_f i_a = K_t i_a \qquad (3)$$

The field winding current (i_f) is constant in armature control scheme.

For normal operation, Newton's laws, the mechanical equation can be described by the following equation,

$$T_m = J\left(\frac{d\omega}{dt}\right) + B\omega + T_L \qquad (4)$$

The transfer function of motor speed with respect to input voltage is expressed as:

$$G(s) = \frac{\Omega(s)}{E_a(s)} = \frac{K_T}{(L_a s + R_a)(Js + B) + K_b K_T} \qquad (5)$$

$$= \frac{K_T}{[L_a J s^2 + (L_a B + R_a J)s + (R_a B + K_b K_T)]} \qquad (6)$$

Simulink model of equation (6) is depicted in figure 2

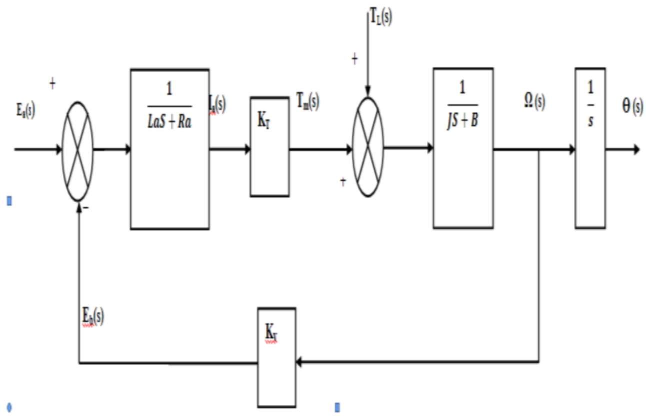

Fig 2: Block diagram of the armature-controlled DC motor.

TABLE I: DC MOTOR PARAMETERS

Parameters	Values	Units
Armature resistance (Ra)	11.4	Ohms (Ω)
Armature inductance (La)	0.1214	Henry (H)
Torque constant (Kt)	1.28	N-m/A
Back emf constant (Kb)	0.0045	V/(rad/sec)
Rated speed (N_m)	1700	Revolutions per minute (rpm)
Moment of inertia (J)	0.12	kg.m2
Frictional coefficient (B)	0.002953	N-m/(rad/sec)
Input Voltage (Va)	240	Volts (V)

B. Fuzzy logic controller Design

I. Input linguistic variable

The reference speed or command speed value is 1400 rpm

The two input variables to FLC are the Speed error (e) and Change in error or derivative of speed error (Δe).

The speed error is expressed as;

$$e = \omega_{ref} - \omega_m \qquad (7)$$

$$\Delta e = \frac{de}{dt} \qquad (8)$$

The controller output called change in control is ω_{sl}.

The 49 IF-THEN statement of the rule base cover a whole universe of discourse according to table II for the design of Fuzzy logic controller (FLC).

e/Δe	NB	NM	NS	Z	PS	PM	PB
NB	NVB	NVB	NB	NBM	NM	NS	Z
NM	NVB	NB	NBM	NM	NS	Z	PS
NS	NB	NBM	NM	NS	Z	PS	PM
Z	NBM	NM	NS	Z	PS	PM	PBM
PS	NM	NS	Z	PS	PM	PBM	PB
PM	NS	Z	PS	PM	PBM	PB	PVB
PB	Z	PS	PM	PBM	PB	PVB	PVB

TABLE II: Fuzzy rule base table for output (w_{sl}) of FLC that execute if then statements

II. PID Controller Model

The PID controller calculates an error value on the basic of difference between the measured motor shaft speed and the desired set point speed (reference speed). The error between the reference speed and the actual speed is given as input to a PID controller and it attempts to minimize the error by adjusting the tuning parameter and gives output or control signal. PID controller output or control signal can be expressed as follows;

$$u(t) = K_p e(t) + K_I \int_0^t e(t) + K_D \frac{de(t)}{dt} \qquad (9)$$

Where u(t) and e(t) are control signal and error signals of the system to be controlled. In Laplace domain (9) gives (10)

$$U(s) = [K_p + \frac{K_I}{s} + K_D s]E(s) \qquad (10)$$

By dividing through by E(s), we get The transfer function is expressed as

C(s) given in (10).

$$C(s) = \frac{U(s)}{E(s)} = K_p + \frac{K_I}{s} + K_D s \qquad (11)$$

The transfer function can be written as,

$$C(s) = K_p\left[1 + \frac{1}{T_I S} + T_D S\right] \qquad (12)$$

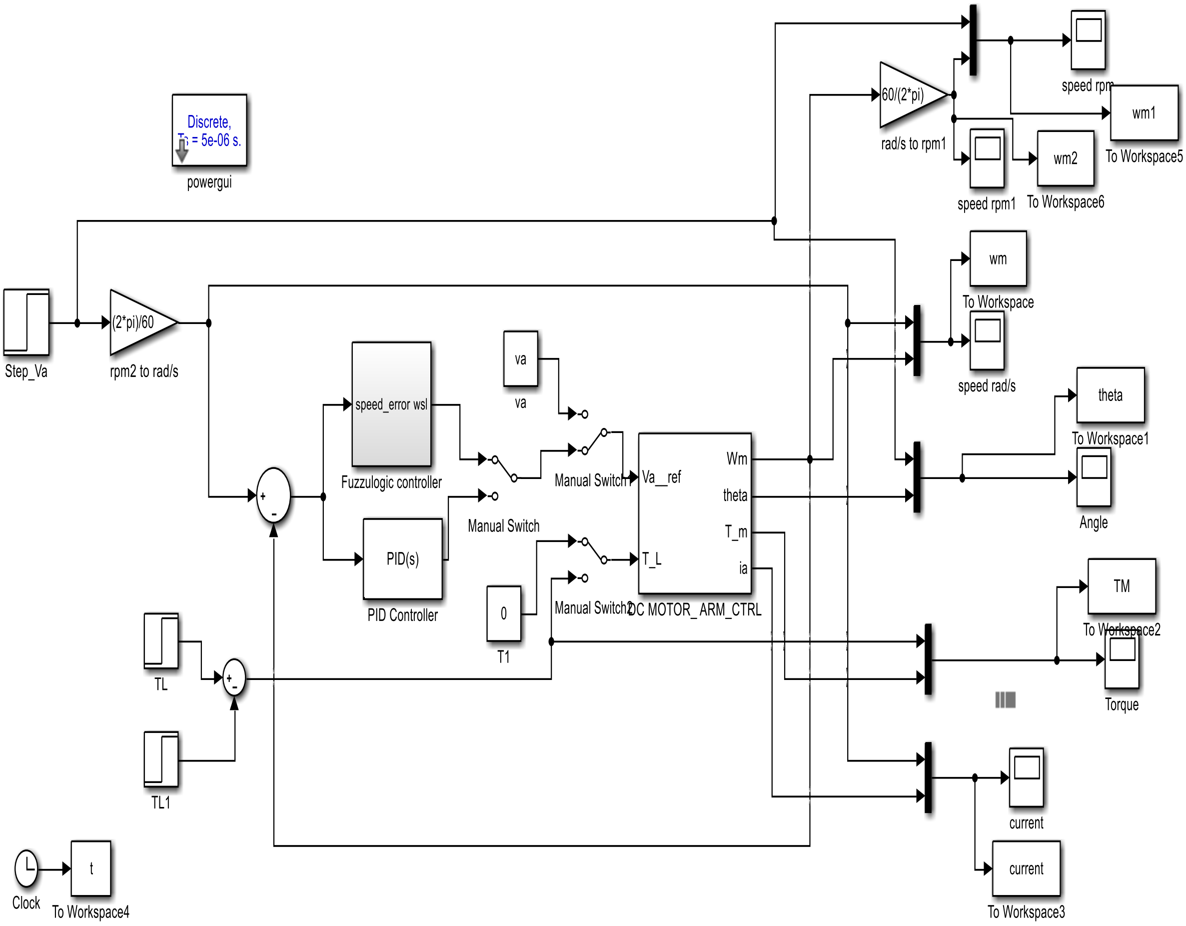

Fig 3 Complete Simulink Model of DC motor with FLC and PID Controller

Where K_p , T_I and T_D are the parameters to be controlled. Zeigler Nichols tuning method is used to obtain their values. Where Kp is proportional gain, K_I is Integral gain, and K_D is derivative gain

From Simulink model in figure 3, The motor is fed by dc voltage source as field current is kept constant, the motor operates using negative feedback control strategy as the motor runs to track or match the reference Speed value of 1400 rpm.

RESULTS AND DISCUSSION

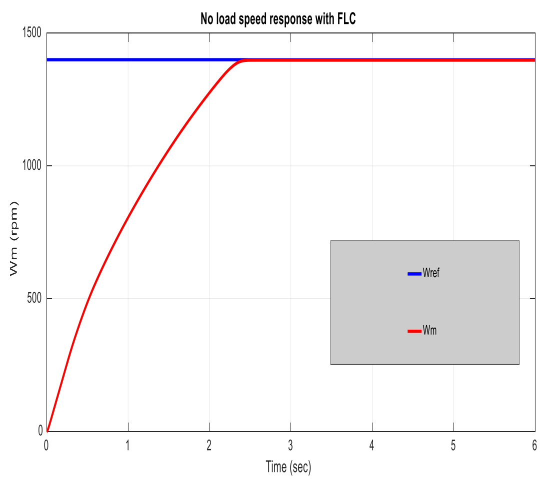

Figure 4 Speed response of SEDCM With FLC

Figure 4 shows fast transient response of the control system with fuzzy logic controller as motor run and attain steady state speed of 1400 rpm to match the reference step speed level as settling time ts =2.4 seconds and no overshoot is observed.

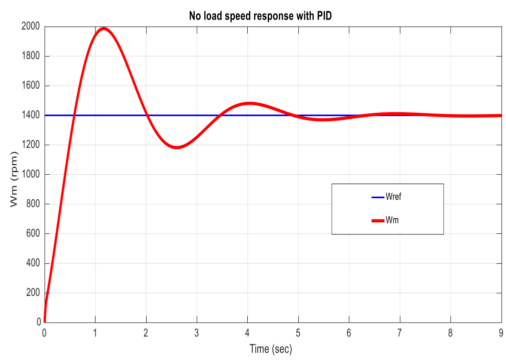

Figure 5: Speed response of SEDCM With PID controller

Figure 5 depicts speed response of the DC motor control system with PID controller as motor run and attain steady state speed of 1400 rpm to match the reference step speed level as settling time (t_s) is 5.2 seconds and 38.6% peak overshoot is observed.

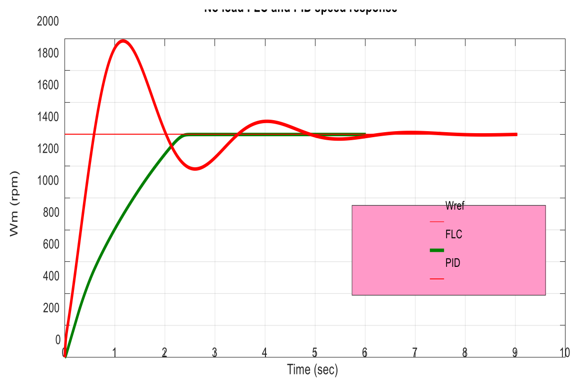

Figure 6 Comparison plots of No-Load speed response of the DC motor control system with PID and FLC

Figure 6 depicts comparison plots of speed response of the DC motor control system with FLC and PID controller as motor run and attain steady state speed of 1400 rpm to match the reference step speed level as settling time ts differs 5.2 and no overshoot with FLC.

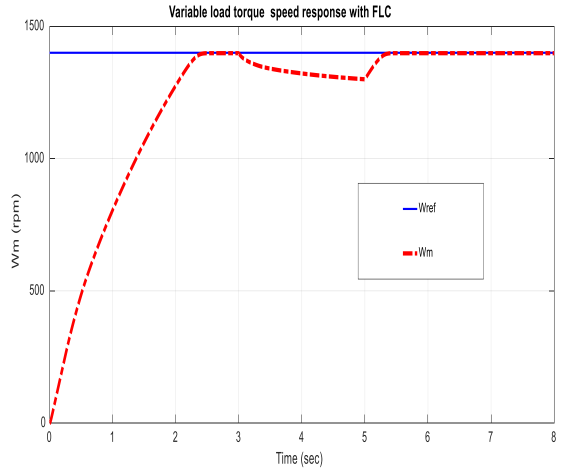

Figure 7 Variable Load Speed response of the DC motor control system with FLC

Figure 7 depicts speed response of the DC motor control system with FLC as motor run and attain steady state speed of 1400 rpm to match the reference step speed level, also, speed value changes when load is applied at time of 3.0 seconds. And returns to reference speed level at 5.4 seconds when the load torque was removed.

Table III: Performance indices of motor speed control system with controllers

Reference speed(rpm)	**Load (Nm)**	**Controller**	**Rise time(seconds)**	**Settling time(seconds)**	**Maximum Overshoot (%)**	**Steady state error**
1400	0	**FLC**	1.6	2.3	0	0
1400	0	**PID**	0.8	5.2	38.6	0

From table III showing The Performance measures of Dc motor drive system, it is noticed that fuzzy logic controller offers better dynamic performance in term of faster settling time of 2.3 seconds and 0% overshoot compared to drive system with PID controller which has undesirable 38.6 % peak overshoot and longer settling time of 5.2 seconds although, rise time is lesser.

CONCLUSION

This paper presents dynamic analysis of a separately excited DC Motor using fuzzy logic. Feedback control system technique is employed to control DC motor. The DC motor speed control system is modeled using PID controller and Fuzzy logic controller in MATLAB/SIMULINK environment. The modeling of DC motor and the controller was done and the performance of Dc motor with each of the controllers was evaluated. A number of simulation results are presented for comparison. Based on simulation results, one can conclude that fuzzy logic controller offers better performance in terms of Speed Reference Tracking as it shows faster settling time, zero overshoot and zero steady state error than that of PID controller.

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